Safe Handling of Coal and other Combustible dusts

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1. INTRODUCTION 276
2. BASIC PRINCIPLES FOR HANDLING PULVERIZED FUELS 278
2.1 Development of Dust Explosions and Fires 278
2.2 Possible Protective Measures against Dust Explosions and Fires 281
3. APPLICATION OF PROTECTIVE MEASURES IN THE INDUSTRIAL ENVIRONMENT286
3.1 Preventive Safety Measures 286
3.2 Explosion Protection Techniques 287
4. LITERATURE 291
4.1 Approximate Values for Explosion Limits and Ignition Temperatures 292

SUMMARY

Dust explosions can only occur when - besides certain marginal conditions - the following factors simultaneously are present:

- Stirred-up, combustible dust
- Oxygen
- Source of ignition

A basic distinction is made between active explosion protection techniques (prevention of the occurrence of explosions) and design related explosion protection (reduction of the effects of explosions).

In practice, the following measures are applied:

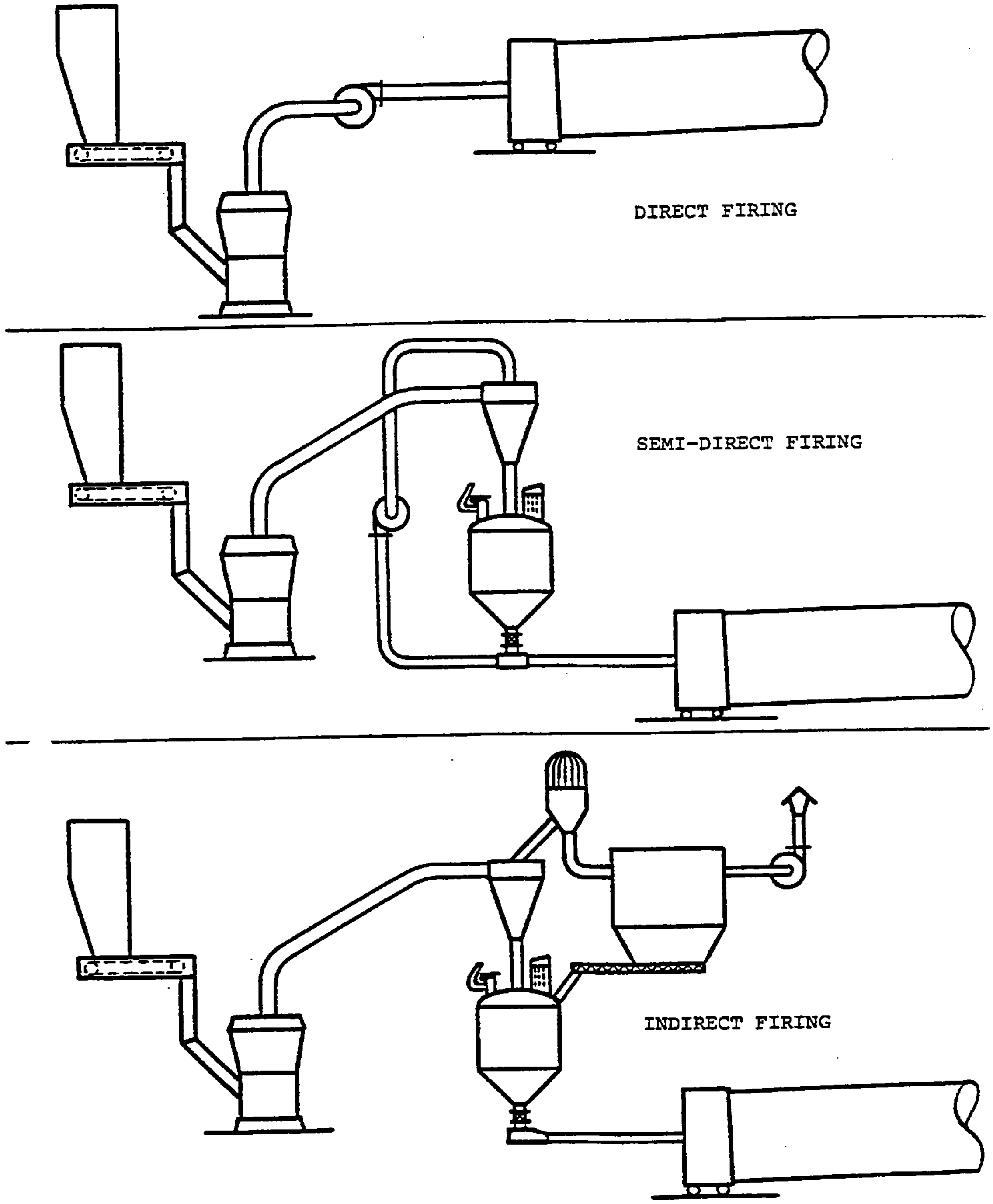
1) **Preventive Measures:**
Their aim is:
   * to exclude possible ignition sources within the installation
   * to prevent the building up of coal dust deposits, wherever possible
   * to detect the source of a fire as soon as possible
   * to extinguish the fire with a minimum of danger

2) **Explosion Protection Measures:**
   * Either active protective measures involving inert gas operation. This is the case when the oxygen concentration within the pulverizing plant is kept below the critical limit - for solid fuels dust, as a rule, less than 12 to 14% - as long as combustible dust is present in the system.
   * Or, alternatively, design related protective measures based on the use of explosion resistant construction in accordance with VDI Guidelines No. 3673.

1. INTRODUCTION

The operational safety of solid fuel plants is an important decision factor when the choice of the preparation system is being considered. For this reason, the three most important basic systems will be briefly reviewed here, differentiated according to their different methods of handling gas and coal dust (Fig. 1).

Fig. 1 Firing Systems



a) Direct firing

In this system, the combustible dust is conveyed into the kiln together with the exhaust gases resulting from the drying-cum-grinding operation. This arrangement represents the simplest design and is easily controllable from the safety point of view. However, there are also considerable disadvantages involved with the use of this system in clinker manufacture with increasing ballast content of the fuel.

b) Semi-direct firing
In this system the combustible dust is separated in an intermediate silo, while the mill exhausts, possibly as recirculated air, are conveyed to the cement kiln as the primary air supply. This results in the technical disadvantages of direct firing being reduced to a certain extent - at the expense of a somewhat more complex installation - but all drying gases are still conveyed to the kiln.

c) Indirect firing
This solution is surely the best possible version when the operation of a rotary kiln is being considered. The pulverized fuel can be conveyed to the firing system from the silo independently from the pulverizing plant operation. The firing system can be operated with a primary air ratio designed for optimal flame generation, as the mill exhaust gases are filtered. Against this we have increased risks with respect to safety due to the operation of the filters and silos and higher control technique requirements.

Further discussion of the decision criteria for the selection of an optimal preparation system is outside the scope of this lecture. However, it is certain that when factors such as

- the growing size of installation
- installations with several firing systems
- the use of fuels rich in ballast
- the use of fuels of widely differing quality characteristics

are considered, the decision will be influenced in favor of the indirect firing system which needs far more advanced and sophisticated safety techniques than the simpler direct firing system does.

For this reason the damage prevention possibilities discussed below refer basically to the indirect firing system and must be adjusted accordingly if they are applied to other systems.

2. BASIC PRINCIPLES FOR HANDLING PULVERIZED FUELS

2.1 Development of Dust Explosions and Fires

In order to effectively ensure the safety of a solid fuel preparation plant, we must first be aware of the sequence of the possible fuel reactions.

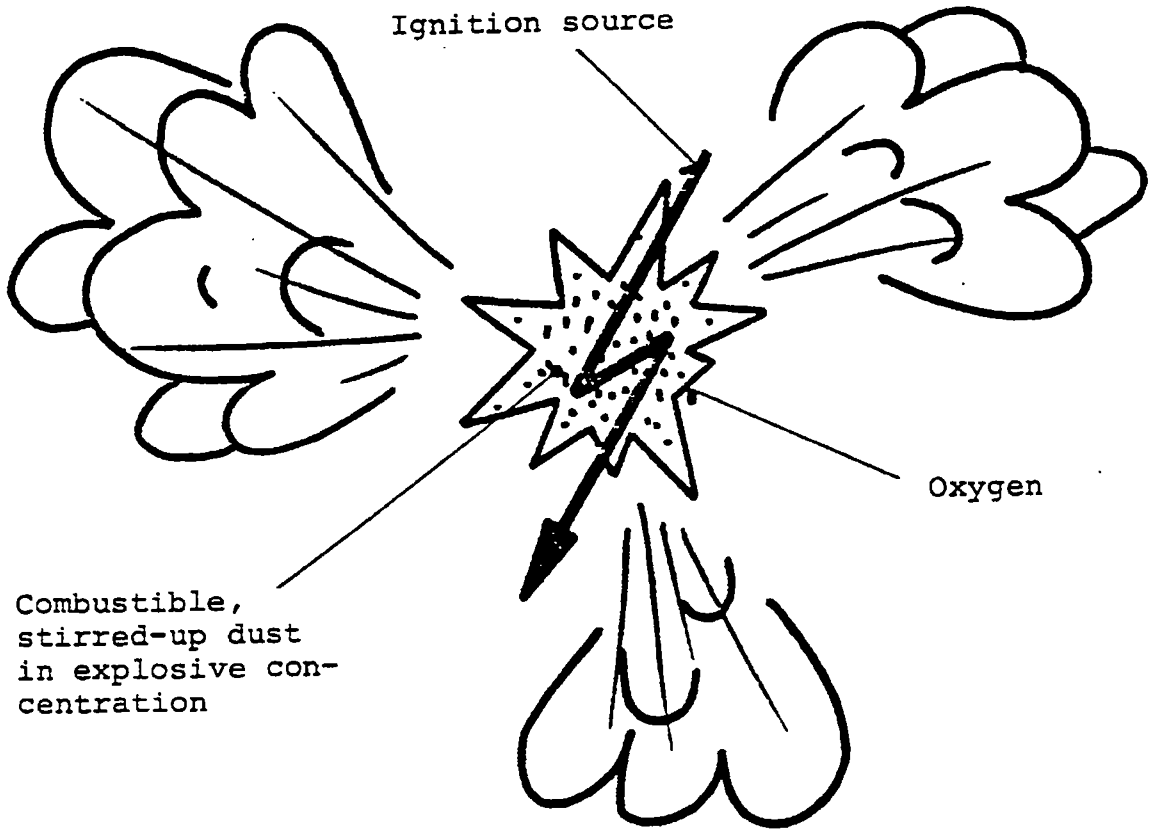
Dust explosions can only occur if the following three conditions are simultaneously fulfilled (Fig. 2).

a) Stirred-up, combustible dust present in explosive concentration.

b) Air or oxygen above the critical concentration, for coal dust as a rule, above 14%, for lignite above 12%.

c) An ignition source possessing energy above the minimal ignition energy (depending upon the type of dust).

Fig. 2 Preliminary Conditions for an Explosion

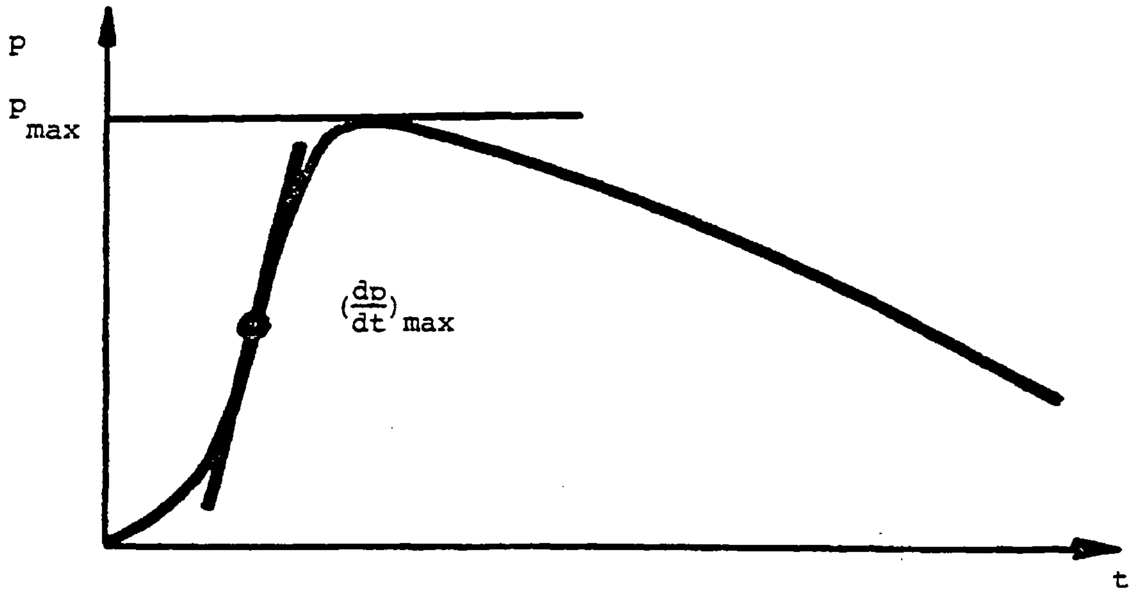


After the ignition of an optimally explosive mixture in an enclosed space, the pressure increases more or less rapidly until it reaches the maximal explosion pressure P_{max}, and then decreases more or less slowly to the original pressure, depending on the aerodynamic conditions (Fig. 3). While the maximum explosion pressure is almost independent of the container's form and size, and in case of coal and lignite dusts, amounts to approximately seven to nine times the initial pressure the maximum rate of pressure rise $\left(\frac{dp}{dt}\right)_{max}$ - which is a measure of the explosion violence - is dependent on the container volume in accordance with the cubic law:

$$\left(\frac{dp}{dt}\right)_{max} \times V^{\frac{1}{3}} = constant K_{st}$$

K_{st} is a material coefficient that depends on the type of dust, the degree of turbulence of the dust/air mixture at the moment of ignition, the grain size distribution, and the type of ignition source. The method for determining K_{St} is given in the VDI Guidelines No. 3673.

Fig. 3 **Pressure Development of an Explosion Over Time**



The degree of explosion violence of dusts is subdivided in industrial praxis into explosion classes, whereby the explosion class and K_{St} are related in the following manner:

Table 1

Dust Explosion Class	K_{St} (bar . m . s^{-1})
St0	0
St1	> 0 to 200
St2	> 200 to 300
St3	> 300

All types of mineral coals as well as the majority of lignites belong to explosions class St1.

Table 2 illustrates arbitrarily selected comparative values for K_{St} characterizing different types of dust.

Table 2

Dust Type	K_{St} (bar . m . s^{-1})
Hard coal	85
Lignite	150
Organic pigments	300
Aluminium	550

This comparison shows, that hard coal dust develops a less violent explosion than aluminium dust.

It must be noted, that the value „K_{St}" does not allow any conclusion as regards the risk involved with that particular dust. The main significance of K_{St} is for the dimensioning of design related protective measures.

Smoldering fires, characterized by slowly smoldering combustion, can occur wherever combustible dust is stored for a longer period of time, whereby the ignition sources can be spontaneous combustion, initiated by external heat sources, mechanical sparks, or electrical sparks and arcs. Combustion propagation in smoldering fires is quite possible in very low oxygen concentrations.

2.2 Possible Protective Measures against Dust Explosions and Fires

In dust explosion protection techniques a distinction is made between active protective measures (prevention of the occurrence of explosions) and design related explosion protection (explosion resistant construction).

2.2.1 Active Explosion Protection

The active explosion protective techniques aim to exclude at least one of the three preliminary conditions necessary for an explosion, i.e.:

- Stirring-up of combustible dust
- Oxygen content above the critical concentration of generally 12% for lignite or 14% for hard coal
- Ignition source

2.2.1.1 Ignition Source

In a pulverizing plant, ignition sources cannot be excluded with absolute certainty. It is always possible that mechanical sparks will be generated by the action of foreign bodies or by friction between moving machine part or that the hot gas or coal feeding system will supply smoldering fuel particles.

2.2.1.2 Combustible Dust

It is of course impossible to replace the combustible dust with a non-combustible material in the preparation of fuel.

Thus, the only remaining possibility is the exclusion of air or oxygen respectively, or the reduction of the oxygen content in the fuel preparation plant.

2.2.1.3 Air and Oxygen

Dust explosions can be effectively prevented through inertization, i.e. the replacement of the oxygen in the air by a non-combustible gas, particularly CO_2 or N_2, if it can be ensured that the inert gas atmosphere will be maintained as long as combustible dust is present in the system.

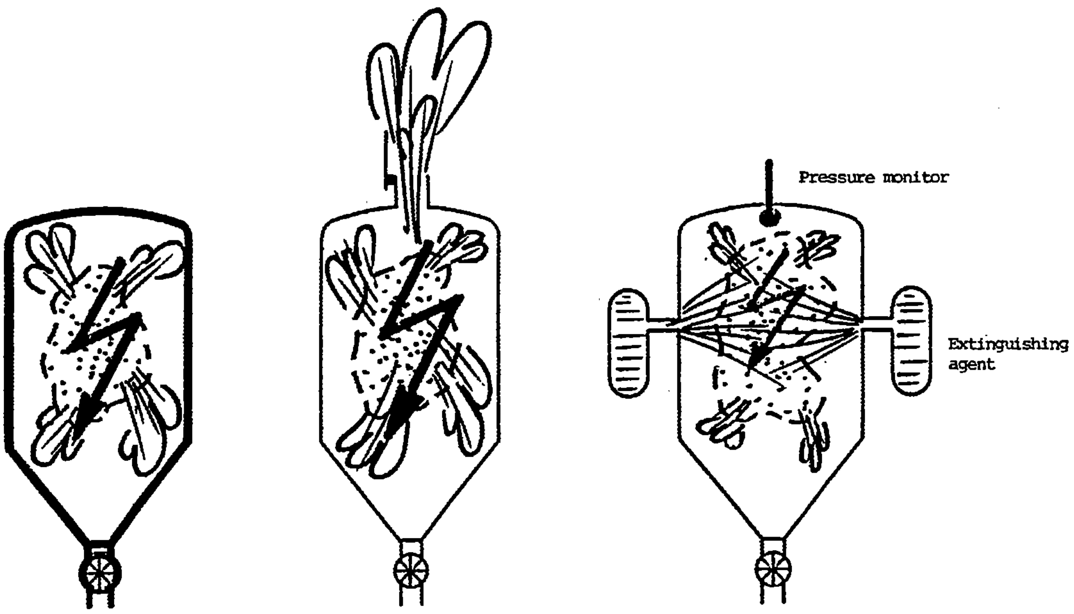
The maximal O_2 concentration, below which no explosive propagation reactions of mineral coal dust are noted, is approx. 14%, the one for lignite approx. 12%. However, this concentration can vary in accordance with the type of fuel processed. As a safety margin of at least 2% O_2 is required, the maximal permissible limit of 0_2 concentration for mineral coal dust is therefore as a rule 12%, for lignite 10%.

2.2.2 Design Related Explosion Protection

Reduction of the effects of already proceeding explosions, and therewith the protection of people and machines, can be achieved by:

- Explosion pressure resistant construction
- Explosion pressure venting measures
- Explosion suppression techniques (Fig. 4)

Fig. 4 Passive Protection Measures



2.2.2.1 Explosion Pressure Resistant Construction

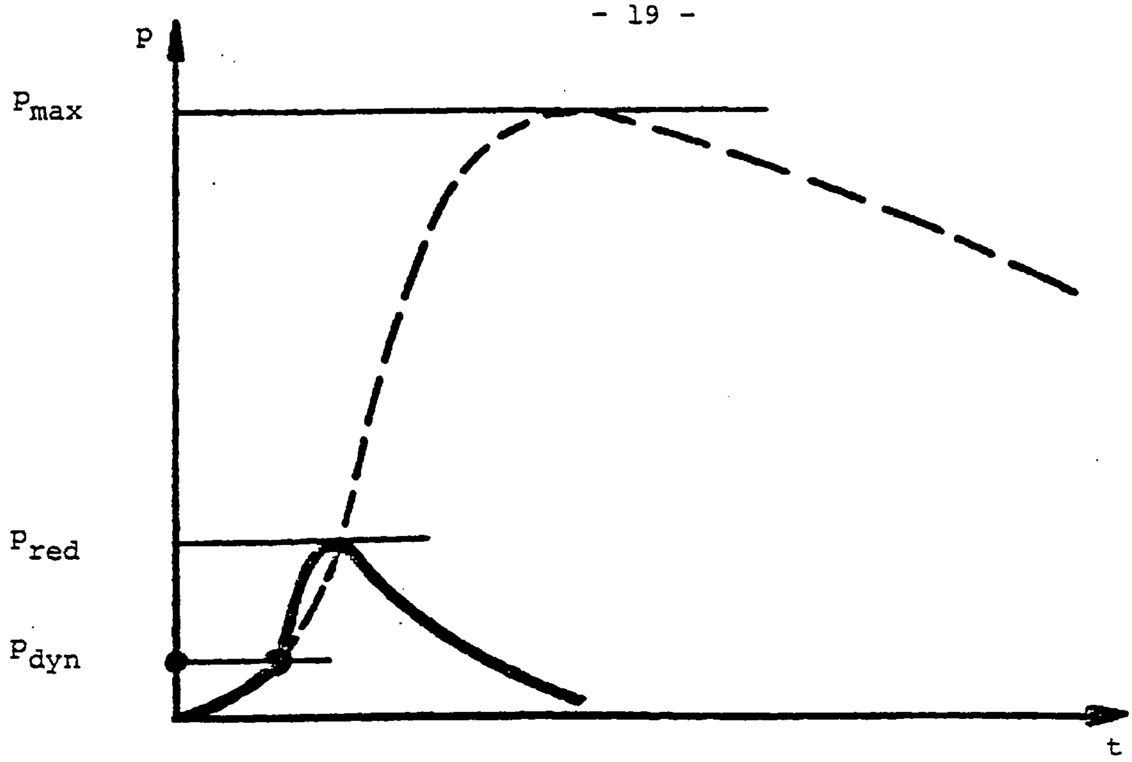
Explosion pressure resistant construction restrict any possible explosion to the dust conveying installation, whereby a certain amount of minor damage to the installation commensurate with the complexity of the facility is accepted.

All dust conveying installation parts as well as the adjacent equipment and sealing elements must be designed to resist the maximal explosion pressure of 9 bar expected in the case of coal or lignite dust. If deformation of the container is accepted, the maximum permissible explosion pressure may be up to 50% above its design value (pressure shock resistant design). A design for 6 bar static overpressure is required for an expected maximum explosion pressure of 9 bar. Such construction methods are of course quite complex and expensive. However, in the event of an accident the installation is again operational within a short time.

2.2.2.2 Explosion Pressure Venting Measures

In a broader sense explosion venting means all measures that serve to open temporarily or permanently the previously closed installation in a safe direction, at the beginning or after a certain spreading of an explosion. The purpose of this is to prevent any overstressing of the mechanical equipment beyond its pressure shock resistance. The strength of the equipment does not have to be designed for P_{max}, but only for the reduced explosion pressure P_{red} (Fig. 5). A deformation of the container may again be acceptable, but it must not burst.

Fig. 5 **Pressure Response in Explosion-Pressure-Relief Techniques**



The explosion pressure venting technique operates in the following manner: When the dynamic response pressure of the pressure venting installation is reached, predetermined breaking points, rip foils or doors open to vent the shock wave outdoors, mainly by means of amply dimensioned discharge channels. Immediately after the pressure venting system responds an increase in the temporal rate of pressure rise can often be observed which is due to the higher turbulence caused during the venting of the shock wave. The pressure rise then quickly stops at P_{red}. Guidelines concerning the design layout and dimensioning of the explosion pressure venting installations are contained in VDI Guidelines No. 3673. If the method of explosion venting is applied not only the inserts of the containers such as filter cloths etc. must be considered but the expected recoil forces as well. With a pressure venting area of 1 m^2, a reduced explosion pressure of 2 bar, and under the assumption that the shock wave escapes with the velocity of sound, a thrust of approx. 15 t acts upon the housing to be protected. This must be properly supported or else the container may be torn from its foundations.

2.2.2.3 Explosion Suppression

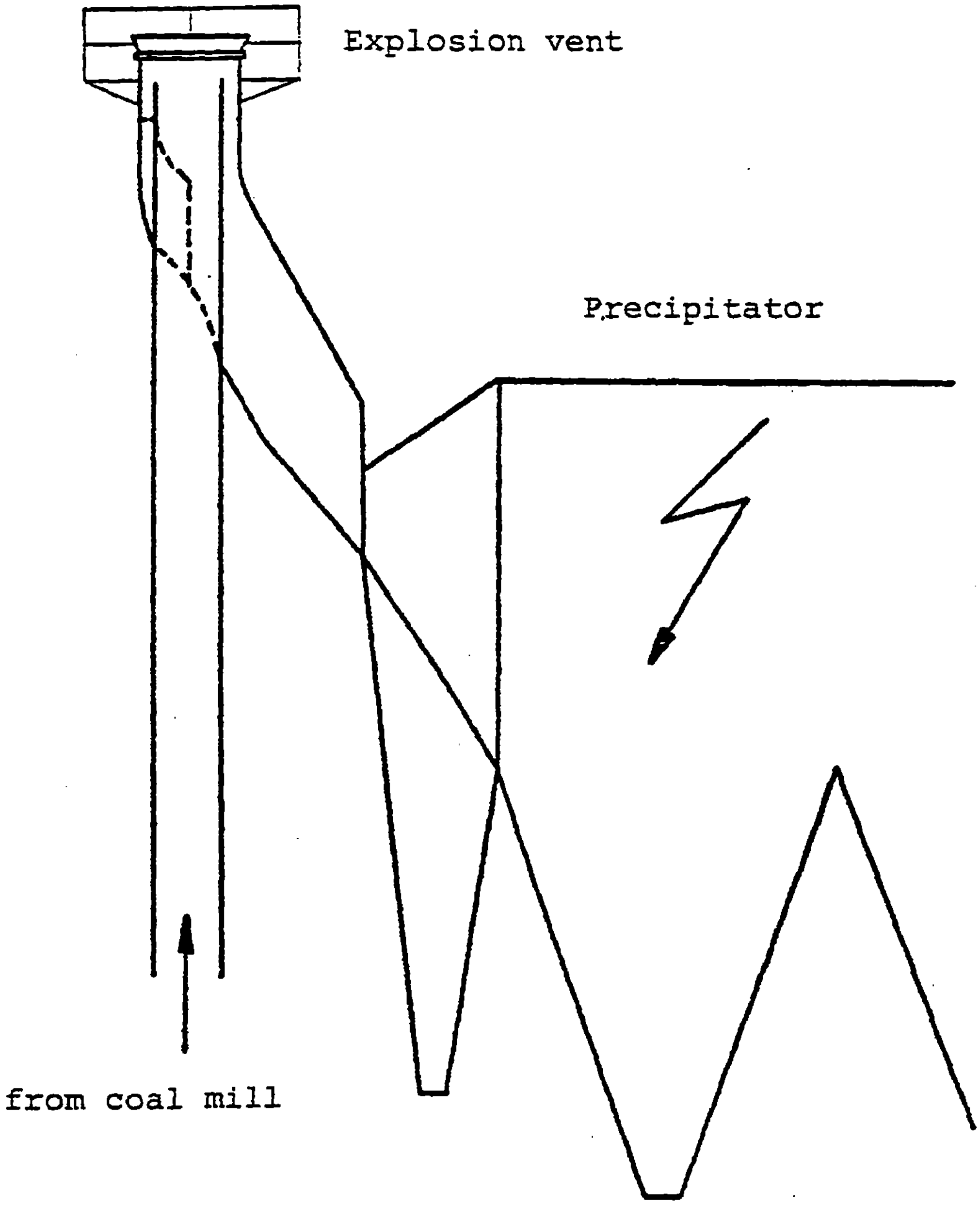
In the explosion suppression techniques, the shock wave preceding the combustion front or the infrared radiation of the combustion area is detected by a device which quickly distributes extinguishing agents under a propellant pressure of 60 to 120 bar by means of detonator-operated valves. With a programmed dynamic response pressure threshold (P_{dyn}) of the detectors, the maximal explosion pressure is again lowered to a reduced level (P_{red}).

2.2.2.4 Limitation: Explosions from Ducts into Containers

The described constructive protection techniques are effective under the condition that the reaction takes place as described in the paragraph 2.1. The description is applicable to most explosions that occur in pulverizing plants. However, if an explosion strikes from a duct into a container, and in doing so the residual dust deposited there is stirred up with great turbulence and ignited, the reaction within the duct and the adjacent container can develop into a detonation of such dimensions that the resulting pressures can amount to 50 times the original pressure, accompanied by a combustion front traveling at supersonic speed, so that any relief or suppression installation is too sluggish in action. However, such events are, fortunately, relatively rare in coal operations. As a limit for a spontaneous explosion propagation, an explosion characteristic of 100 bar.m.s^{-1} was observed under particular conditions in a 200 m long pipeline of 1800 mm diameter located at the experimental mining research station in Dortmund, while the usual values for coal are generally lower (approx. 85 bar.m.s^{-1}).

However, if the principles of design related explosion protection are to be consequently pursued, every duct conveying combustible dust in an explosive concentration and whose length exceeds five times its diameter must be safeguarded by an explosion vent placed ahead of its inlet into a container (such as a filter) (Fig. 6). Through this any explosion originating in the pipeline will be vented so that the protective measures taken with respect to the adjacent container can be designed in accordance with the criteria of an explosion starting in the container itself.

Fig. 6 Venting of a Duct in Front of a Precipitator



2.2.3 Prevention of Smoldering Fires

Smoldering fires in dust deposits are best prevented by preventing the possibility of greater quantities of dust accumulating. This is achieved through the appropriate design and slope of surfaces, pipelines and supports, as well as sufficiently high gas speeds within the conveyor systems.

In silos where great quantities of combustible dust are stored for the plant's own specific purposes, any combustion that may occur must be detected as early as possible by carefully monitoring of the dust temperature and the CO content of the silo atmosphere so that proper countermeasures can be taken.

3. APPLICATION OF PROTECTIVE MEASURES IN THE INDUSTRIAL ENVIRONMENT

The fire and explosion protection measures described above result for practical applications on the one hand in a network of preventive safety measures that significantly reduce the risk of an accident in the operation of combustible dust installation, and on the other hand in actual explosion protection techniques that can prevent explosions, or at least shall hold the explosions within acceptable limits.

3.1 Preventive Safety Measures

The primary aim of preventive safety measures is to exclude possible ignition sources as causes of conflagration or explosion if at all possible. In addition, they are also intended to prevent secondary damage caused by the expulsion or stirring up of vast quantities of dust and their subsequent ignition.

These essentially preventive safety measures can be listed as follows:

- Temperature measurement of
  - mill exhausts
  - stored dust, preferably in silo entry and exit
- CO analysis of
  - the silo atmosphere in silos
  - mill exhaust after the filter
- Prevention of local overheating caused by friction in conveyor belt systems, high speeds of screw conveyors, bucket elevators, rotary valves, and bearing, and/or the detection of increasing temperatures by measuring techniques. Relative velocities of moving parts < 1 m/s are considered safe, > 10 m/s are considered as potential ignition sources.
- Spark separators in air heaters
- Metal separator prior to the mill
- Prevention of electrostatic discharges by conductive connections and grounding of all installation parts
- Prevention of arcing in electrofilters by appropriate voltage control measures
- Prevention of dust accumulation possibilities:
  - All surfaces to have a slope of at least 70° to the horizontal plane, especially in filter or silo cones
  - Regular disposal of dust deposits
  - Gas speeds in conduits of more than 22 m/s
- Protection of the stored dust from the effects of external heat, for instance by spraying the silo externally with cooling water
- Provision of inert gas supplies (e.g. CO_2) for inertization of the silos in the case of smoldering fires
- Cleanliness of operating rooms
  - Effective removal of the dust generated by means of proper dedusting installations
  - Safe elimination of dust deposits by means of suitable auxiliary material

From the point of view of safety a solid fuel pulverizing plant must be operated as continuously as possible, as critical situations often arise when the plant is not in operation. This fact must be considered when the capacity of the installation is being decided upon.

3.2 Explosion Protection Techniques

3.2.1 Inert Gas Operation

As described under 2.2.1, active explosion protection in solid fuel pulverizing is practically limited to inert gas operation, i.e. operation with a maximum of 10 to 12% oxygen in the pulverizing plant, depending on type of fuel, as ignition sources and the stirring-up of dust can never be excluded with absolute certainty.

Active explosion protection can be applied if hot inert gases such as the kiln exhaust from cement kilns or hot gases from a combustion chamber, combined with a corresponding design for the mill's recirculation gas are available. In the last case the dew point problem becomes significant, therefore this solution is rarely applicable for very moist fuels, or special measures will have to be taken for drying of the circulation gases.

If the inert gas atmosphere can be maintained with absolute certainty through appropriate design and interlocking of the installation for as long as combustible dust is present in the system, design related protection measures become in principle redundant. In those cases where these conditions cannot be guaranteed, for example, because hot gases with higher oxygen content are being used such as clinker cooler exhausts, or because of dew point problems, design related explosion protection techniques must be rigorously applied.

3.2.2 Explosion Pressure Resistant Construction

Explosion pressure resistant construction, i.e. the dimensioning of the installation section to resist maximal explosion pressure, are mainly applicable where pressure venting methods cannot be used at all or only with difficulty, for geometrical reasons.

This is mostly the case in mills, and definitely in all conduit pipe systems where the length of the system exceeds five times the tube diameter. As a rule such components are designed to withstand a static overpressure of 10 bar.

3.2.3 Explosion Pressure Venting Measures

All combustible dust conveying components that are not in themselves designed to be explosion pressure resistant, such as cyclone, filters, pulverized fuel silos, etc. are to be provided with properly dimensioned devices for explosion pressure venting. Thereby containers and all interconnected aggregates such as bin vent filters, etc. must be dimensioned in pressure shock resistant design to withstand the reduced explosion pressure.

Explosion venting openings within a particular building must be connected to properly dimensioned exhaust channels leading into the open. In order to prevent an explosion originating in the mill spreading into the filter via the conduit pipe, the conduit pipe must be equipped with an explosion vent in front of its connection to the filter. This measure is not required for pneumatic conveying systems as in this design the dust concentration is normally above the explosion limit. In addition, the minimal ignition energy is significantly higher under the operating conditions of pneumatic conveying than it is in the case of stirring-up combustible dust in containers.

The area containing the vent opening for explosion pressure venting must not be accessible to anyone when the installation in operation.

VDI Guidelines No. 3673 can serve as a basis for the design of such an explosion pressure venting system. Naturally, the system must be inspected regularly.

3.2.3.1 Underpressure Protection

After venting an explosion in very large enclosures such as pulverized fuel silos through explosion flaps considerable underpressure can develop inside the silo due to dynamic effects and due to cooling down of the hot gases remaining in the silo after the explosion. Typical examples for the size of underpressure valves are given in Table 3. Guidelines for the individual design of underpressure valves can be taken from the relevant literature (10).

Table 3

Volume	m^3	100	1000
Diameter	m	3.4	.5
Cylindrical length	m	9.5	22.0
Plate thickness	mm	6	8
Max. negative pressure	mbar	100	25
Required aspiration area	m2	0.1	1.0

3.2.4 Explosion Suppression

Techniques of explosion suppression can basically replace all the previously mentioned methods. However, in practical experience it has been seen that in pulverizing plants, the costs involved in the consequent application of explosion suppression techniques are significantly higher than they are for explosion pressure venting techniques and explosion pressure resistant construction methods, both with respect to procurement and maintenance of the sensitive equipment.

Thus applicability of explosion suppression may be primarily limited to existing, insufficiently protected pulverizing plants whose retrofitting in accordance with alternative protection techniques would be entirely uneconomical.

3.2.5 Fire Extinguishing Measures

If an accumulation of considerable quantities of combustible dust can be prevented inside the actual pulverizing plant (except in pulverized fuel silos), any fires that may arise following an explosion will not be able to grow to any significant size. The installation of a fire extinguishing system can nevertheless still be recommended for cloth filters and electofilters.

In the case of smoldering fires in pulverized fuel silos, all further fuel supply must be stopped immediately. Following this, the silo exit must be made airtight and the silo atmosphere flooded with CO_2. Sufficient time must now pass until the temperature conditions have normalized. An underpressure valve is required in order to avoid collapsing of the silo due to the vacuum produced during cooling down. The above procedures can take several days, depending on the size of the smolder location. An alternative technique is to deliver the fuel as quickly as possible to the burner system via the dosing and conveyor systems. Of course this method is possible only when the dosing and conveying systems are heat-resistant, dustproof and explosion resistant. In addition, under no circumstances is glowing fuel to be returned to the silo, as for instance via overflow feeders.

Fig. 7 shows the practical preventive safety measures for pulverized fuel silos. In Fig. 8 the application of design related protective measures for solid fuel preparation is illustrated.

Fig. 7 Preventive and Safety Measures for Coal Dust Silos

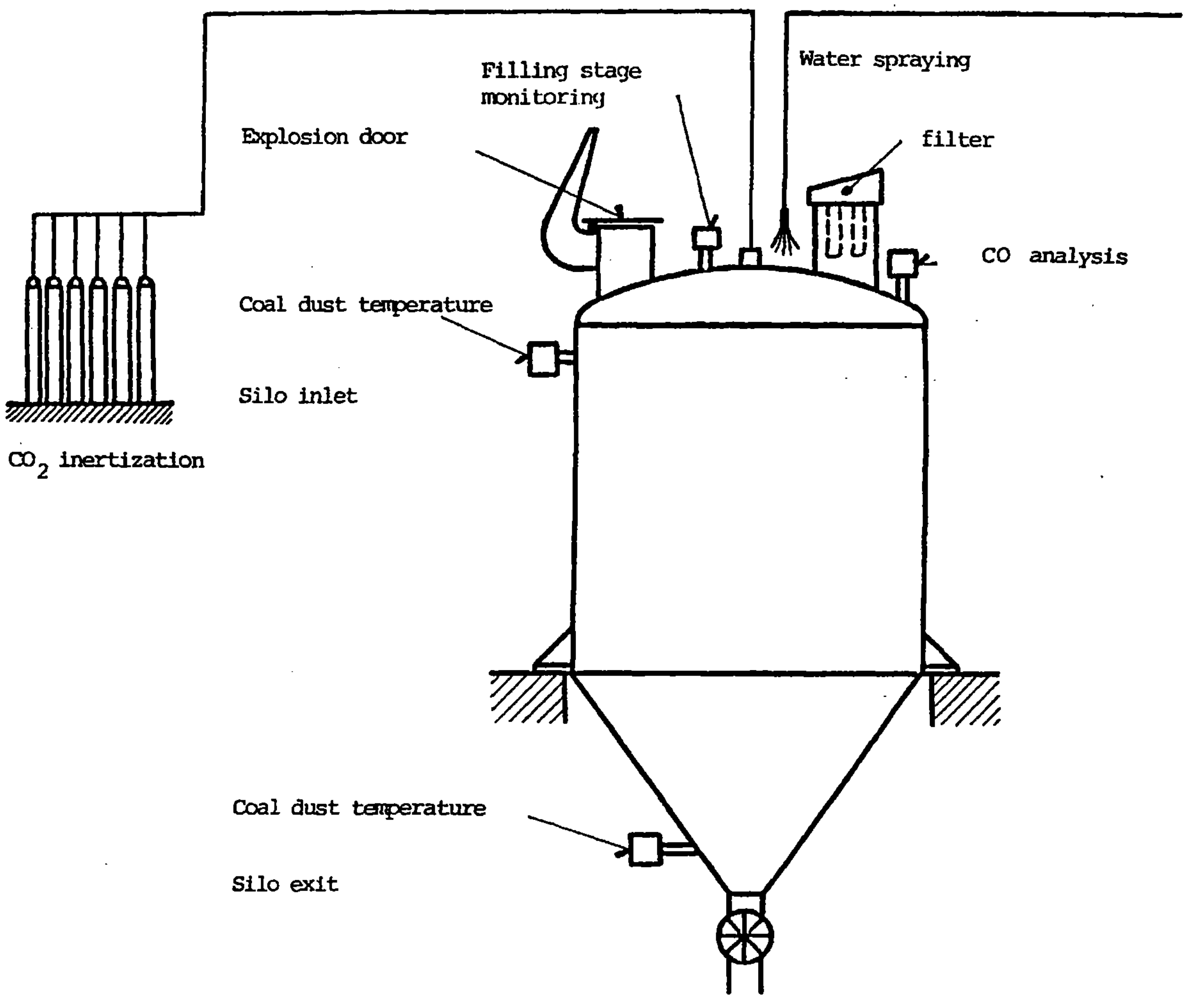
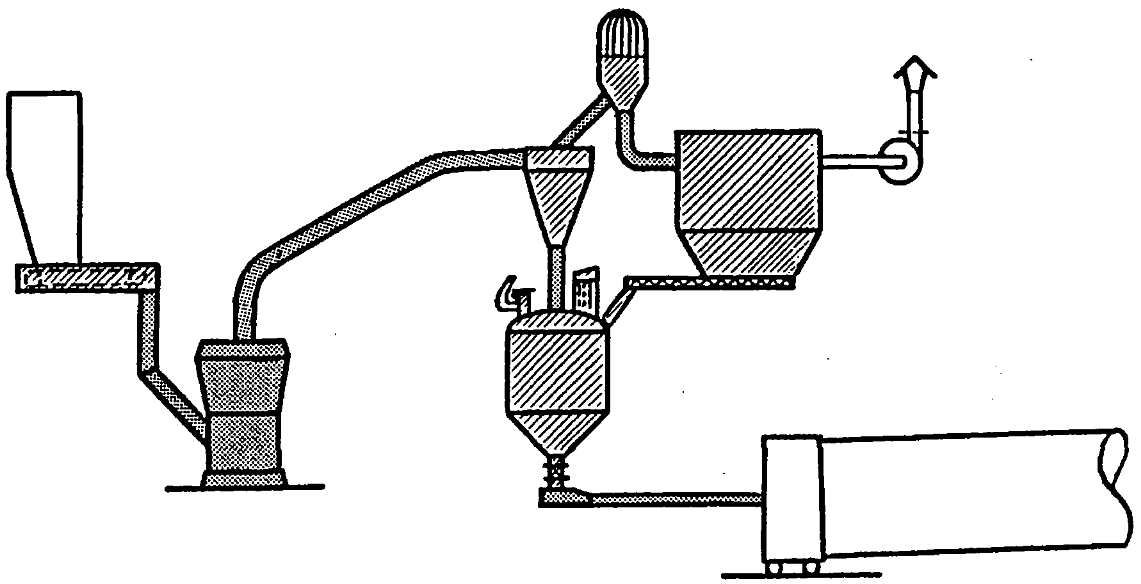
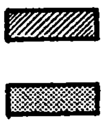


Fig. 8 **Example to Show the Application of Design Related Explosion Protection**





Explosion pressure vented, pressure-shock-resistant

Explosion pressure resistant (ND 6)

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4.1 Approximate Values for Explosion Limits and Ignition Temperatures

The numerical values of the following data are depending on the test procedure applied and can vary within certain limits according to the origin and geological age of the coals. The following values refer to the Literature (9).

- Explosion Limits

1) Dust concentration:
   * lower explosion limits 40 to 130 g/m3
   * upper explosion limits 2000 to 6000 g/m3

2) Oxygen concentration:
   * hard coal 14%
   * lignite 12%

3) Concentration of non-combustible parts (ash):
   * hard coal (-medium volatile bituminous) 65%

- Ignition Temperature

	Cloud °C	Layer °C
Lignite	380 to 450	225 to 300
Hard coal	590 to 710	245 to 380
Petrol coke	690	280